in use in the pacific northwest

PACIFIC NORTHWEST FOREST AND RANGE EXPERIMENT STATION
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MOISTURE CONTENT OF GLULAM TIMBERS IN USE IN THE PACIFIC NORTHWEST

by

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INTRODUCTION

Glulam members in buildings and other structures are increasingly exposed to a wide range of weather conditions across the Nation and to an expanding variety of interior extremes in buildings of special occupancy. The latter includes such diverse environments as occur in interior swimming pools, shower rooms, skating rinks, freezer rooms, food processing and storage rooms, laundries, and many others.

Little is known about the extent of moisture content variations which occur in heavy structural members under these conditions, although we do know moisture content has an important influence on strength, durability, and dimensions. The purpose of this study is to provide reliable data to the timber fabricating industry as a basis for the review and expansion of recommended design standards.

Up to the fiber saturation point, most strength properties of wood decrease markedly as moisture content increases. Current timber design practice provides for reductions in working stresses of from 10 to 33 percent in various strength properties when moisture content exceeds 16 percent (*5*)[1]--in normal interior occupancies or arid exposed conditions, the engineer can assume that moisture content usually will not exceed 16 percent. However, in many interior uses, and in most exterior weather-exposed situations, high humidity exists and the engineer is obliged to substitute a conservative assumption for knowledge. The result of this approach is usually inefficient design, unduly increasing costs and encouraging the use of structural materials other than wood.

The durability of glued laminated members depends upon both the adhesive and the wood. Again, where moisture content is expected to exceed 16 percent for any appreciable period, the use of more costly, exterior adhesives is current industry practice (*1*). The point at which the wood should be treated is sometimes conservatively placed at 16-percent-moisture-content level, although it is probable that no decay hazard exists below 20-percent moisture content and it is only above the latter point that American Institute of Timber Construction standards indicate treatment (*3*).

Dimensional changes across the grain of glulam members may be appreciable if their moisture content changes greatly in use. Incompatibilities with other materials, inequalities in surfaces, and cracking of materials may result. In addition, unsightly checking in the wood surfaces follows large or repeated variations in moisture content, and when exposed, such cracks may admit water and increase the hazard of decay.

Although equilibrium moisture content can be accurately predicted for uniform humidity and temperature conditions of long duration (*6*), the range of moisture content in large sections exposed to variations of weather is unknown. Sun and rain assault wood surfaces with wide swings of vapor pressure, but changes in the interior may be slow, depending upon the type and integrity of wood surfaces and the retarding influence of coatings. Under the best conditions, moisture content extremes can be minimized by effective coatings, which reduce the rate of moisture gain or loss. But at unprotected end-grain surfaces and in many types of connections, adjustments to the moisture environment are rapid and complete.

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[1] Italic numbers in parentheses refer to Literature Cited, p. 21.

The Forest Products Laboratory, in cooperation with regional Forest Service Experiment Stations of the U.S. Department of Agriculture, has initiated a field survey of national scope to study moisture content in structural members over a wide range of environments. This program receives the cooperation and advice of member firms of the American Institute of Timber Construction and contemplates a series of observations over several years. Local climatic conditions will be fully considered in this coordinated study, reflecting program objectives of the Forest Products Laboratory and other regional research units. It is believed that the data obtained will be of value in improving structural efficiency, durability, and design.

This is a progress report of moisture measurements during the first 2 years of this study in the Pacific Northwest region. The time and sample size to date are too limited to justify definite conclusions on climatic influences, which must await the complete observations of the national survey. However, the preliminary indications are of wide interest in a growing industry, being the first compilation of use conditions in an organized, formal study. They are published now to invite the industry to help guide the continuing program into channels which will result in conclusions of the greatest practical value.

An effort has been made in this report to identify conditions, due to design, which are conducive to inadequate performance of glulam members in use and to isolate some of the factors contributing to this performance. Design solutions are needed now, and a wider awareness of environmental influences can be a useful guide to the designer, pending the more complete results of the extended study.

MOISTURE SENSORS

A remarkably simple and effective device for measuring moisture contents in wood is described in a recent report of the Forest Products Laboratory (*4*); it provides a new means of obtaining accurate moisture content readings deep in heavy sections without destroying or impairing the function of the member. This moisture sensor can be inserted to any practical depth in a 3/16-inch-diameter hole drilled into a structural member. It can be left in place in remote parts of a member, and repeated readings over an extended period can be made by bringing the leads to a convenient point (fig. 1).

The sensor, or probe (fig. 1), is a small rectangular piece of wood coated on two opposite faces with conductive silver paint. The silver electrodes thus formed are connected by wire leads to a resistance-type moisture meter, which measures the electrical resistance of the small wood block directly and the moisture content of the surrounding wood of the structural member indirectly. Very fine insulated wires, about 30 gauge and 70 feet or more long, may be used to effect readings at an accessible point, since the resistance of the wires is small in relation to that of the sensor. The probes are calibrated to read moisture content in Douglas-fir at a temperature of 70° F., and have a resistance range which may be read directly on a commercial moisture meter with an accuracy of ± 1-percent moisture content. The wood element is treated with a 10-percent solution of pentachlorophenol in methanol to maintain its accuracy in a moist environment for an extended time.

Because the range of weather and temperatures is appreciable in this study, auxiliary thermocouple probes in the wood have been used. Thermocouple installations in adjacent holes determine temperatures within the member, regardless of weather fluctuations. Thermocouples are of laboratory-quality copper-constantan design with matching leads and may be read directly on a temperature-compensated potentiometer. The accuracy of the system is ± 2.5° F., which is well within that needed for moisture content corrections.

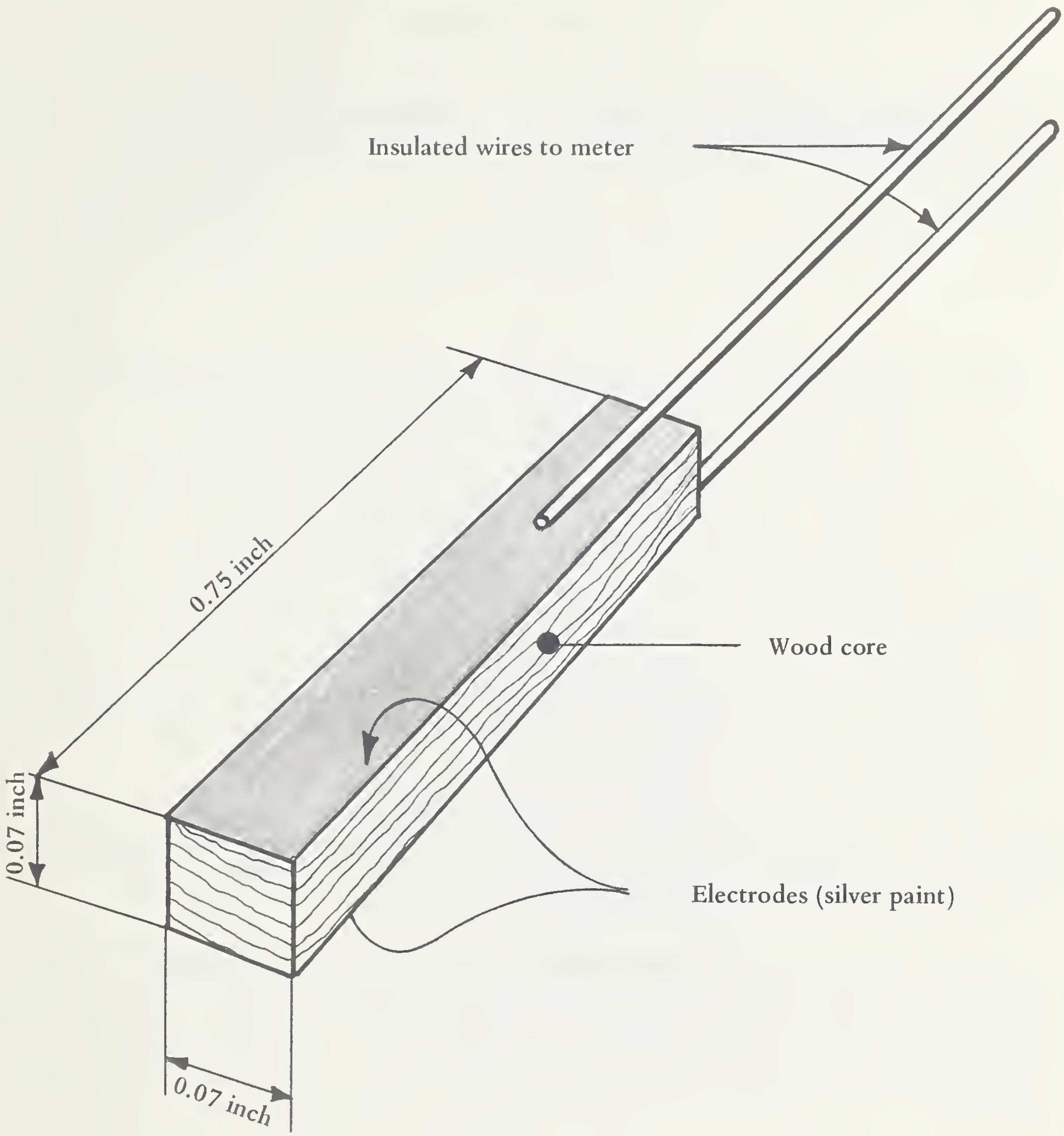


Figure 1.--Moisture sensor, as described by the U.S. Forest Products Laboratory.

INSTALLATION

Installation of the measuring devices in the selected structures required preliminary testing of methods and the cooperation of owners. Visits were made to each structure to tentatively select probe locations and obtain authorizations. Cooperation was readily extended in all cases, but sometimes depended upon reasonable expectations that the work would not interfere with building activities, not be visually objectionable, nor cause structural weakening. The appearance factor had to be considered, though the size of the holes needed in the members was well within design allowances for grade characteristics and did not significantly weaken the sections.

Moisture sensors were prepared and calibrated by the Forest Products Laboratory and required only a simple continuity test prior to installation. Thermocouples were locally made and soldered and checked against standard instruments or known temperatures.

The type of installation used in the Pacific Northwest had thermocouples separately placed, and fixed, color-coded insulated wires extended to ground level so that repeated readings could be made more easily. A typical pattern of "shell" and "core" sensors with a thermocouple, placed at both the top and bottom of a member, is shown in figure 2. This pattern of six probes was usually followed, except that only a single set of three probes was used in locations where readings at top and bottom served no useful purpose. The three-probe group became a basic wiring component, whose four wires were twisted into a cable in advance with an electric hand drill. These wires were spliced and soldered to the short leads of the two sensors and thermocouple in the circuit shown, staggering and taping the series of connections. Vinyl tape was used, colored to match and blend with the wood or wood finish, and small cushions of the same tape protected wires at fastenings.

Placement of the probes and wiring was arranged with a contractor known to have carpenters experienced in timber construction and capable of the care needed. The contractor furnished the necessary tools and equipment to do the work under Forest Service supervision, and provided required liability protection to the owners.

Holes of 3/16-inch diameter were drilled in the side surfaces of members to a depth three-eighths inch beyond the center, or to a maximum of 5 inches where the width exceeded 9 inches. Holes were cleaned of shavings with the drill, and moisture sensors were carefully inserted to the full depth by their own light leads. Over the sensor, a ball of treated, nonabsorbent cotton batting was lightly tamped with a 1/8-inch wood dowel. The insertion of the sensor and the cotton barrier required deftness and care to avoid damage at the fragile connections.

A moisture seal was provided at the cotton barrier by placing a bead of fast-drying cellulose nitrate cement against it. This was accomplished by squeezing about 3/4-inch length of the cement into one end of an ordinary soda straw, inserting the straw into the hole, and blowing the cement out from the opposite end. A syringe could also be used for this purpose. Wood filler was used to plug the hole at the surface and exclude water.

Thermocouples were similarly installed, except that no moisture seal was needed, and the hole was fully filled with cotton batting for insulation. Figure 2 illustrates placement of both sensors and thermocouples.

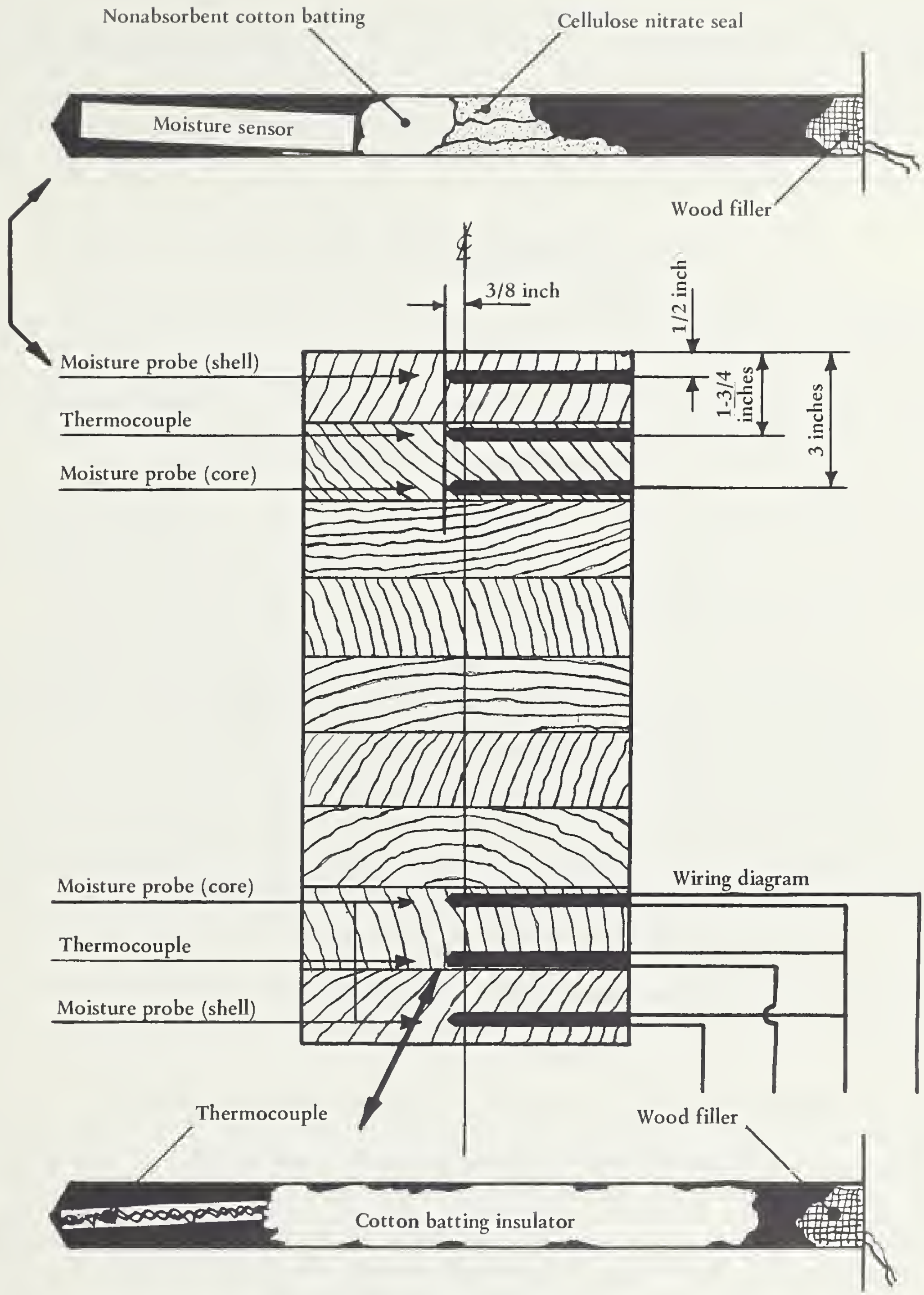


Figure 2.--Typical section showing placement of moisture probes and thermocouples and method of installation.

Where fixed wire leads were used, special precautions were needed to protect them against vandalism, accidental damage, and the weather. The lower ends of the cables were either concealed or hung in coils above reach. In exterior installations, wires were brought down the north faces of columns or walls, and housings were provided for terminal coils. Vulnerable areas in wire insulation were additionally sealed with a silicone coating. Efforts to conceal and protect the installations were not entirely successful, and it will be noted that readings had to be terminated at locations D4 (p. 16) and F2 (p. 18) because of damage to the wiring.

DESCRIPTION OF SUBJECTS

The choice of subject installations was made in consultation with representatives of the American Institute of Timber Construction, who could readily refer to appropriate examples. Geographically, the subject locations were selected to reflect the variety of weather influences prevailing in western Oregon and western Washington. Moisture sensors have been placed in members fully exposed to the weather, with different solar orientations, and in partly protected locations; also, in sections near exposed end grain and near connections.

Interior environments, more or less isolated from weather by building enclosures, are represented by various business and commercial building types. Severe, special interior occupancies include an interior swimming pool, a shower room, two ice skating rinks, a freezer room, and food processing and storage rooms.

The environmental range of these initial subjects is broad, but no exhaustive study of all possible use conditions has been attempted. Rather, the intention has been to make selective installations to identify problem conditions which may merit more detailed investigation later. The subject list may be expanded during the course of the study, if indicated, or after an evaluation of regional results by the Forest Products Laboratory.

Many installations are close to major U.S. Weather Bureau stations, so that results may be compared with detailed local weather data over a period of time. Three timber species are represented in the subjects: Douglas-fir, redwood, and western redcedar.

All members are Douglas-fir except:

1. All building A members are clear heartwood redwood.

2. All structure C members are western redcedar.

3. Locations D6 and D7[2] are in 4- by 6-inch western redcedar roof decking.

These moisture readings have been grouped arbitrarily under the following general types of exposure in an effort to classify use environments as much as possible:

I. Exterior exposed members--members with one or more surfaces largely exposed to the exterior atmosphere and to alternate wetting and drying by rain and sun.

II. Exterior protected members--members exposed to the exterior atmosphere but sheltered from alternate wetting and drying.

[2] Codes identifying structures and location of sensors are given in the following section, p. 7.

III. Enclosed members, normal occupancy--interior members enclosed within a complete building shell and conditioned to a normal heated environment for human occupancy.

IV. Enclosed members, special occupancy--interior members enclosed within a complete building shell and exposed to special moisture and temperature environments.

OBSERVATIONS

The structures chosen in the Pacific Northwest are as follows, the prefix letters being those used in the tables for identification:

A. First National Bank of Oregon, Seaside, Oregon, Branch

B. Public Market, Seaside, Oregon

C. Sign structure, Somerset West, near Portland, Oregon

D. George C. Marshall Community Center, Vancouver, Washington

E. Silver Skate Ice Rink, Portland, Oregon

F. Washington Canners Coop., Vancouver, Washington

G. Ice Pavilion, Bellevue, Washington

Members are numbered serially in each building; suffix letters indicate top, bottom, north, or south locations in a member.

Shell and core designations are for sensors placed one-half inch and 3 inches, respectively, from the narrow face of the members, as illustrated in figure 2. North and south or top and bottom designations are for identification only, and depths are otherwise illustrated.

Moisture content readings were begun in July 1966 on a quarterly basis, but after a series of five such readings, a semiannual frequency was adopted as satisfactory to reflect major seasonal changes.

The measurements have been corrected for temperature and for wood species up to tabulated values of 30 percent. Reasonable extrapolations of test data for these corrections were made for temperature corrections of readings over 25 percent and species corrections of value over 20 percent, since laboratory data do not presently cover these ranges. This was done to avoid an artificial gap in the results between 20 percent and 30 percent, which would occur if corrections were neglected entirely. The method used was related to known fiber saturation levels, limiting possible errors, but all results over 25 percent should be regarded as indicative, anyway, since the moisture meter itself is less accurate in the higher range.

It was judged adequate for the practical purposes sought in this study to round all corrected figures below 25 percent to the nearest whole numbers and values of 25 percent and above to the nearest 5-percent moisture content.

I. EXTERIOR EXPOSED MEMBERS

Under severe rainfall and humidity conditions, moisture in unprotected exterior members may reach excessive levels. A strong seasonal influence is evident in the observed results, though high moisture content persists in some locations where end grain, connections, or moisture pockets exist. Some figures, which may appear inconsistent, are believed to be associated with large checks which permit rainwater to enter readily, particularly in structure C and member G4. Interesting exceptions also appear in structure C, where locations C8, C9, C11, and C12, close to unprotected, unfinished, and noticeably checked vertical ends, do not consistently show very high moisture contents. These locations dry rapidly as well as absorb rapidly, but the pattern of moisture so far observed is not readily reconciled with the north and south orientations of the two ends. Additional data and inspection of these conditions may help to resolve the questions presented.

Northwest coastal area

Member		Percent moisture content						
		July 15, 1966	Sept. 21, 1966	Feb. 3, 1967	April 25, 1967	July 12, 1967	Jan. 23, 1968	July 26, 1968
A1T	Shell	10	10	12	17	10	12	10
	Core	11	11	12	18	11	12	11
A1B	Shell	12	12	13	12	13	12	13
	Core	12	12	12	12	12	19	17
A3	Shell	12	12	12	12	12	19	12
	Core	11	11	12	12	12	12	16
A2	North	8	12	20	11	13	18	13
	South	10	11	20	11	13	17	13
A5T	Shell	16	13	16	14	12	13	13
	Core	12	11	12	11	11	11	11
A5B	Shell	12	11	18	16	8	9	12
	Core	12	13	22	16	13	12	6
A6S	Shell	13	5	12	11	6	9	6
	Core	13	12	23	21	16	16	10
A7	Top	12	11	18	16	13	16	13
	Bottom	11	11	18	55	14	15	13

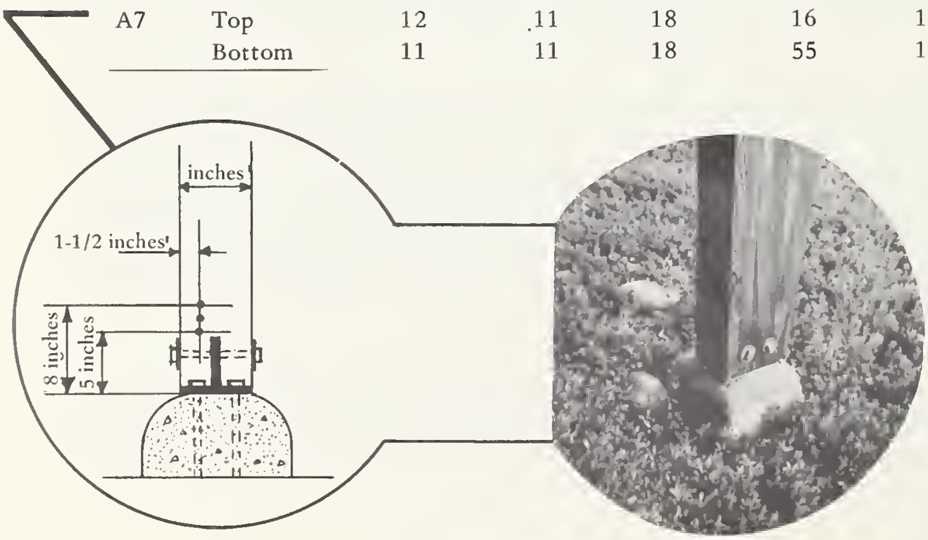


Figure 3.--Column base. (First National Bank, Seaside, Oregon.)

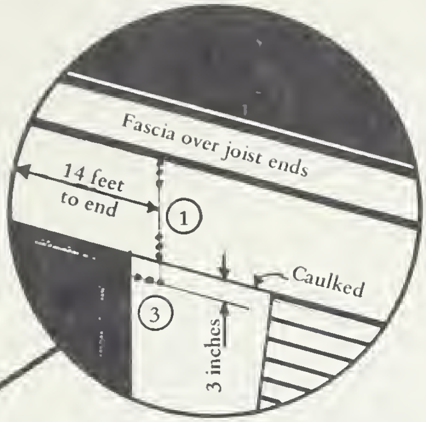


Figure 4.--Exposed beam-column joint facing ocean storms. (First National Bank, Seaside, Oregon.)

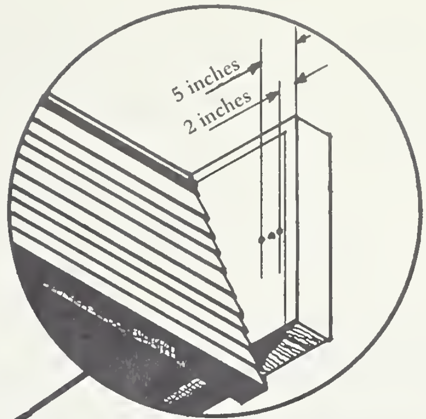


Figure 5.--Exposed beam end with copper cap. (First National Bank, Seaside, Oregon.)

Figure 6.--Measurements in beam facing east, near center column. (First National Bank, Seaside, Oregon.)

Figure 7.--Measurements just outside 2- by 4-inch louvre hanger. (Ice Pavilion, Bellevue, Washington.)

Puget Sound-Willamette Valley area

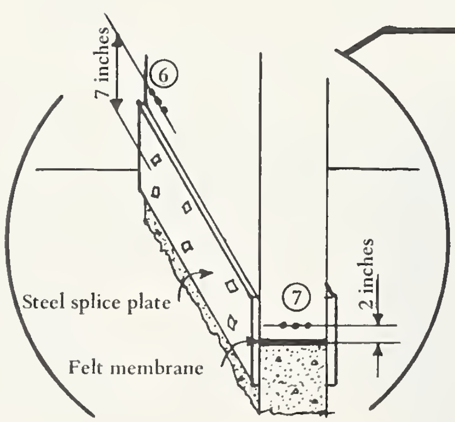
Member		Percent moisture content							
		July 15, 1966	Sept. 21, 1966	Feb. 3, 1967	April 25, 1967	July 12, 1967	Sept. 20, 1967	Jan. 23, 1968	July 26, 1968
G4T	Shell	–	–	–	35	17	19	30	17
	Core	–	–	–	35	20	14	35	25
G4B	Shell	–	–	–	30	16	15	50	14
	Core	–	–	–	30	17	15	19	18

Puget Sound-Willamette Valley area–Continued

Member		Percent moisture content						
		July 15, 1966	Sept. 21, 1966	Feb. 3, 1967	April 25, 1967	July 12, 1967	Jan. 23, 1968	Sept. 20, 1968
C10T	Shell	10	10	30	13	5	30	18
	Core	14	13	13	14	13	40	18
C10B	Shell	12	10	16	30	7	15	17
	Core	14	13	13	13	10	14	15
C1	South	10	14	45	55	6	55	40
	North	10	45	65+	65+	5	45	40
C2	South	14	13	45	17	13	15	40
	North	15	13	65+	65+	14	65+	65+
C3N	Shell	12	11	14	45	10	14	65+
	Core	14	14	65+	13	14	65+	65+
C3S	Shell	8	10	45	13	8	65+	50
	Core	14	12	12	16	12	14	40
C11	Top	9	10	13	11	8	14	14
	Bottom	9	10	12	15	8	12	12
C12	Top	9	9	9	8	6	14	14
	Bottom	8	8	8	7	6	12	13

Figure 8.--SE column base.

Figure 9.--Crossbeam notched for main beam.



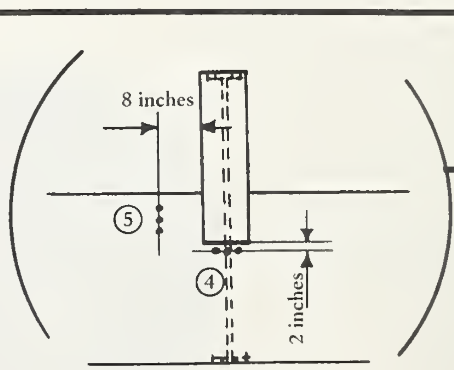
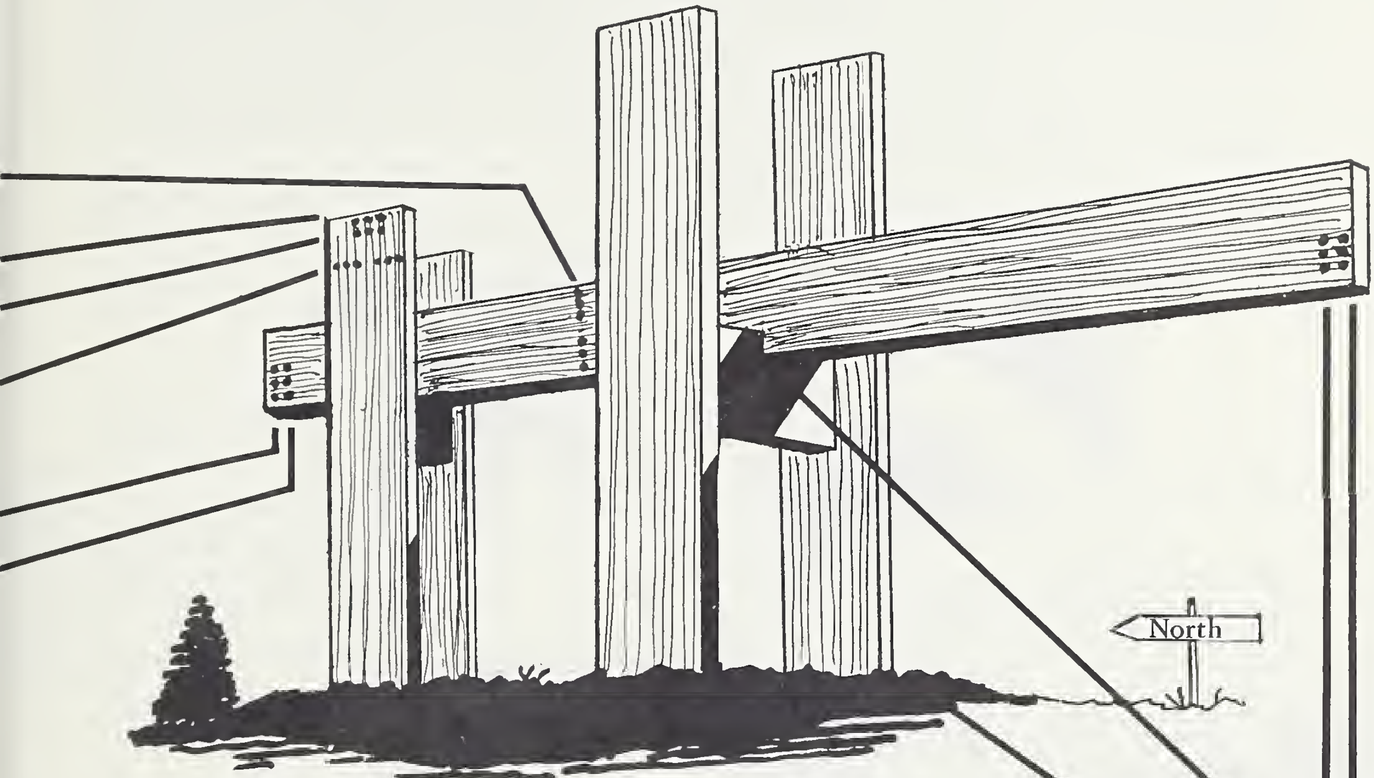


Figure 10.--Exposed sign structure of 14-1/2 by 53-1/2-inch unfinished western redcedar, near Portland, Oregon.



Puget Sound-Willamette Valley area–Continued

Member		Percent moisture content						
		July 15, 1966	Sept. 21, 1966	Feb. 3, 1967	April 25, 1967	July 12, 1967	Jan. 23, 1968	Sept. 20, 1968
C6	Shell	12	11	65+	50	7	14	65+
	Core	17	15	15	15	15	65+	17
C7	East	17	14	30	30	13	18	16
	West	45	45	60	45	17	17	65+
C4	East	45	35	55	45	40	65+	14
	West	16	12	18	17	11	60	13
C5	Top	16	13	15	15	14	14	15
	Bottom	15	13	15	15	14	14	15
C9	Top	14	11	12	13	12	14	50
	Bottom	11	10	10	11	8	12	17
C8	Top	7	9	10	8	6	9	40
	Bottom	10	9	17	8	6	13	18

II. EXTERIOR PROTECTED MEMBERS

Exterior members, effectively protected from rain and sun and sheltered adequately to prevent the absorption of water, would not be expected to reach high moisture content levels in the Northwest. The moisture content range found in member D2 is believed to be typical for this climate, and additional installations are planned to verify this. The special character of building G has been noted, and if the high moisture levels found in members A6 and B3 are significant, the significance is principally in emphasizing the difficulty of judging when a member is effectively protected.

Figure 11.--Though partly protected by overhang, moisture feeds in from end-grain surface. (Public market at Seaside, Oregon.)

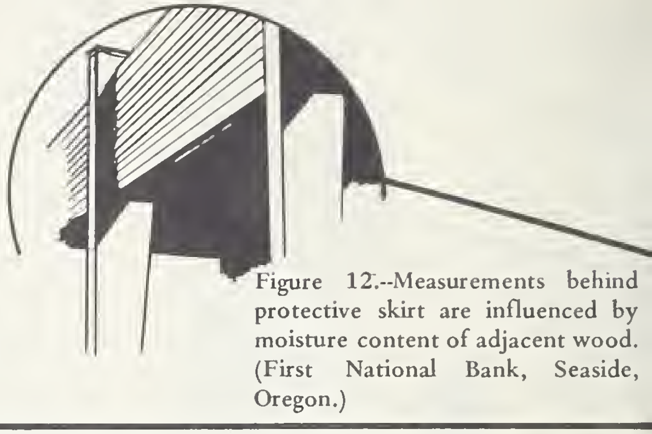


Figure 12.--Measurements behind protective skirt are influenced by moisture content of adjacent wood. (First National Bank, Seaside, Oregon.)

Figure 13.--Measurements at center of wide porch overhang indicate that this portion is well protected from sun and rain, even though unprotected ends absorb moisture. (George C. Marshall Community Center, Vancouver, Washington.)

Figure 14.--Fully protected from sun and rain, these beams are subject to continuous circulation of exterior air through large roof ventilators and side louvres. Seasonal operation of ice rink from late September to early May probably materially increases severity of exposure. (Ice Pavilion, Bellevue, Washington.)

Member A6 is, in fact, largely exposed to the weather, but an opportunity occurred here to compare the moisture levels outside the protective skirt, as indicated for location A6S on page 00, with opposite location A6N inside the skirt and 8 inches above the lower protective edge. It appears here that the shelter furnished one portion of the member is largely bypassed by moisture movement through the wood for a distance of some 8 inches (fig. 12).

Location B3, shown in figure 11, appears reasonably sheltered, particularly in the top probe locations, and the projecting end of the beam is capped with copper. However, there is a filler block at the end of the beam to create an illusion of greater depth, and the joint shown probably admits water. Also, it should be noted that the copper cap extends just flush with the soffit of the beam and has no drip edge. It appears likely that water is absorbed at this edge by capillary action, and possibly along the sides of the cap.

Northwest coastal area

Member		Percent moisture content							
		July 15, 1966	Sept. 21, 1966	Feb. 3, 1967	April 25, 1967	July 12, 1967	Sept. 20, 1967	Jan. 23, 1968	July 26, 1968
A6N	Shell	11	11	21	15	14		17	15
	Core	8	11	12	12	12		12	12
B3T	Shell	12	12	25	19	15		25	15
	Core	16	17	18	18	18		23	19
B3B	Shell	15	17	13	16	16		40	45
	Core	16	17	25	18	18		35	35

Puget Sound-Willamette Valley area

Member		Percent moisture content							
		July 15, 1966	Sept. 21, 1966	Feb. 3, 1967	April 25, 1967*	July 12, 1967	Sept. 20, 1967	Jan. 23, 1968*	July 26, 1968
D2T	Shell	13	10	13	11	9		13	10
	Core	10	10	11	10	9		11	9
D2B	Shell	10	10	12	10	10		13	10
	Core	10	10	12	10	10		13	9
G1T	Shell	–	–	–	14	14	11	22	7
	Core	–	–	–	15	11	–	23	7
G1B	Shell	–	–	–	24	19	15	30	17
	Core	–	–	–	30	19	16	35	18
G2T	Shell	–	–	–	17	12	13	65+	11
	Core	–	–	–	17	15	14	23	14
G2B	Shell	–	–	–	25	19	16	25	18
	Core	–	–	–	25	11	14	25	10
G3	Shell	–	–	–	30	12	11	40	10
	Core	–	–	–	20	15	12	30	14

*Building G members, only, influenced by ice in shelter on these dates.

III. ENCLOSED MEMBERS, NORMAL OCCUPANCY

Normal interior exposures, where the building is enclosed, heated, and not excessively ventilated, are rather consistent in producing a low moisture content level with little variation. Climatic areas appear to have little effect here, though a slight seasonal influence may be detected by comparing averages for the heating season against results for the more open summer season. Member E3, shown in figure 17, exhibits slightly lower moisture contents as well as surface evidence of excessive drying in the form of checks.

Northwest coastal area

Member		Percent moisture content						
		July 15, 1966	Sept. 21, 1966	Feb. 3, 1967	April 25, 1967	July 12, 1967	Jan. 23, 1968	July 26, 1968
A4T	Shell	8	9	7	7	8	7	8
	Core	7	8	7	7	7	7	7
A4B	Shell	7	9	7	7	7	7	7
	Core	7	9	7	7	7	7	7
B1T	Shell	9	9	7	7	8	7	7
	Core	8	8	7	7	7	7	7
B1B	Shell	7	9	7	7	7	7	7
	Core	8	8	7	7	7	7	7
B2T	Shell	8	9	8	7	8	8	8
	Core	7	7	7	6	5	6	6
B2B	Shell	8	8	7	7	7	7	7
	Core	7	8	7	7	7	7	7
B4T	Shell	8	8	8	7	8	8	8
	Core	8	8	8	7	7	7	7
B4B	Shell	8	9	8	8	8	8	8
	Core	9	8	8	7	7	7	7

Puget Sound-Willamette Valley area

Member		Percent moisture content						
		July 15, 1966	Sept. 21, 1966	Feb. 3, 1967	April 25, 1967	July 12, 1967	Jan. 23, 1968	July 26, 1968
D1T	Shell	9	9	7	7	7	8	7
	Core	9	8	7	7	7	8	7
D1B	Shell	8	9	7	7	7	7	8
	Core	8	9	7	7	7	7	7
D3T	Shell	9	9	9	8	8	8	8
	Core	9	9	8	8	8	8	8
D3B	Shell	8	8	7	7	7	7	7
	Core	8	8	8	8	8	7	7
E3T	Shell	6	7	7	6	6	7	7
	Core	7	7	7	6	7	7	7
E3B	Shell	7	7	6	7	6	7	7
	Core	6	7	6	7	6	7	7

Figure 15.--Probes are located just inside shaded glass front of air-conditioned food market. (Public market, Seaside, Oregon.)

Figure 16.--About halfway up center roof leg of these rigid frames in a gymnasium, measurements do not indicate any significant moisture increase due to human activity and audience loads. (George C. Marshall Community Center, Vancouver, Washington.)

Figure 17.--Located at the top of a staircase and near a fan ventilator, this beam in a heated banquet area of the Silver Skate Ice Rink is very dry and noticeably surface checked. (Portland, Oregon.)

IV. ENCLOSED MEMBERS, SPECIAL OCCUPANCY

Special occupancies produce a wide range of moisture and temperature environments which may be largely isolated from climatic influences by the building shell. These range all the way from a sports structure, like the Houston Astrodome where human moisture from the perspiration and expiration of large crowds may be an important influence, to a small laundry where steam processes are used. Clearly, the severity of these exposures on wood structural members will vary with many factors, among them the moisture source, temperature, the character of the building enclosure, air circulation, and air conditioning. The continuity of the environment may also be important, and this may make coatings or finishes useful in retarding changes in moisture content. In effect, special occupancies and all related conditions create their own climate or "weather," and the range of these climates is becoming increasingly important as timber is more widely used in all kinds of buildings.

Public swimming pool

Member		Percent moisture content							
		July 15, 1966	Sept. 21, 1966	Feb. 3, 1967*	April 25, 1967	July 12, 1967	Jan. 23, 1968	July 26. 1968	REMARKS
D4	Inside	11	10	--	--	--	--	--	Shower
	Outside	11	10	--	--	--	--	--	spray
D5T	Shell	10	10	11	11	10	10	10	Glulam
	Core	10	10	11	10	10	11	10	rigid frame
D5B	Shell	10	10	10	10	10	10	10	over
	Core	10	10	11	10	10	10	10	pool
D6	East	9	9	10	10	9	10	9	4" x 6"
	West	8	8	10	9	8	9	8	Western red-cedar deck
D7	East	8	8	10	10	8	10	8	over
	West	9	9	9	9	8	9	9	pool

* Relative humidity by wet-bulb 61 percent, temperature approximately 80° F.; equilibrium moisture content 10.9 percent.

Public ice skating rink

Member		Percent moisture content							
		July 15, 1966	Sept. 21, 1966	Feb. 3, 1967	April 25, 1967	July 12, 1967	Jan 23, 1968	July 26, 1968	REMARKS
E1T	Shell	10	11	14	11	10	11	10	
	Core	11	11	13	11	11	11	11	
E1B	Shell	14	14	15	14	14	14	14	Occupancy
	Core	14	14	14	13	13	13	13	temperature approx. 40° F.
E2T	Shell	12	13	16	13	11	14	12	Automatic
	Core	12	13	15	12	11	12	11	dehumidifier used
E2B	Shell	15	14	16	15	15	14	15	
	Core	15	15	17	14	14	16	15	

The potential variation in interior environments considered, there are evidently no simple answers to their control. One objective of this study is to explore their character by use of a sensitive material as a measure of the vapor pressure environment. The indications so far are limited but important. Results in building D strongly indicate that moisture conditions in an enclosed swimming pool can be controlled. It is believed that a combination of air circulation and an unintended kind of dehumidification by condensation on large glass walls are effective here. Moisture readings in building E indicate that vapor pressure in an enclosed ice rink can be

Figure 18.--Probes are located at middepth of 2-3/8 inches thick glulam seat board, placed 6 inches apart. Seats are exposed to intermittent spray from showers in center, but room is well ventilated. (George C. Marshall Community Center, Vancouver, Washington.)

Figure 19.--Location 5 is at top and bottom of glulam roof leg of rigid frame over pool; locations 6 and 7 are in 4- by 6-inch western redcedar roof deck. Continuous condensation on large glass areas may help to keep vapor pressure and moisture content low. (George C. Marshall Community Center, Vancouver, Washington.)

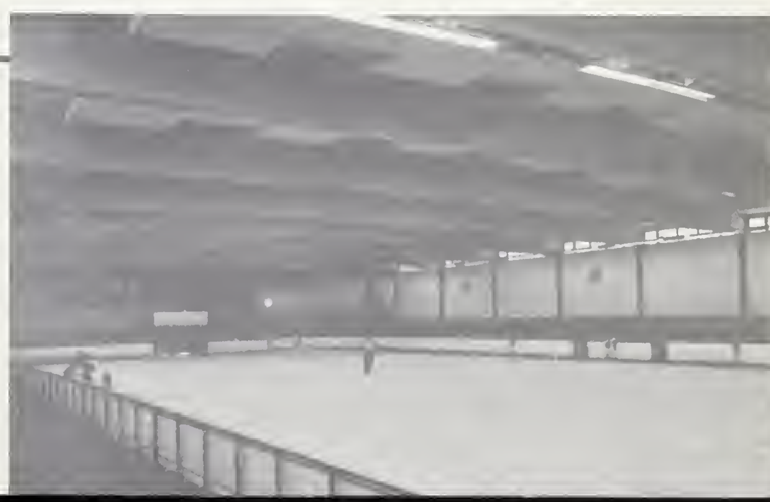


Figure 20.--Automatic dehumidifiers were installed in this rink to correct a prior condition of dripping from the beams onto the ice. No condensation is now seen on beams, and moisture content is held to a reasonable level. (Silver Skate Ice Rink, Portland, Oregon.)

held to tolerable limits, in some contrast to the evidence in building G where water continually drips onto the ice from the roof structure. The means of assuring adequate control of moisture under varying influences requires much additional study, but the possibility of doing so is already evident.

This portion of the current study is indicative rather than exhaustive, in consideration of some of the environmental spaces known to be of special concern to designers. Immediate plans are being made to expand this phase of the study to identify further the moisture conditions encountered and the critical factors which produce them. Additional installations are contemplated in a continuously operating, low-temperature room and another enclosed swimming pool.

Wet food processing

Member		Percent moisture content							
		July 15, 1966	Sept. 21, 1966	Feb. 3, 1967*	April 25, 1967*	July 12, 1967	Jan. 23, 1968*	July 26, 1968*	REMARKS
F1T	Shell	14	16	11	10	18	11	11	12- by 30-inch
	Core	14	16	11	10	14	11	10	sawn beam
									over
F1B	Shell	20	19	11	10	19	8	9	wet
	Core	35	25	13	12	25	12	12	sorter
F2T	Shell	14	14	10	9	16	--	--	11½- by 32½-
	Core	14	12	11	10	12	--	--	inch glulam
								--	beam near
F2B	Shell	18	20	11	10	14	--	--	cookers
	Core	12	15	12	11	12	--	--	(steam)

*Processing not in operation on these dates.

Refrigerated food storage*

Member		Percent moisture content							
		July 15, 1966 (Fruit, 75%, -10°)	Sept. 21, 1966 (Fruit, 50%, 35°)	Feb. 3, 1967 (Fruit, 10%, 35°)	April 25, 1967 (Potatoes, 100%, 35°)	July 12, 1967 (Fruit, 25%, 35°)	Jan. 23, 1968 (Washing, 0%, 60°)	July 26, 1968 (Fruit, 5%, -13°)	REMARKS
F3T	Shell	19	25	15	20	21	25	30	
	Core	13	21	20	16	16	25	18	
F3B	Shell	15	14	16	18	19	25	25	
	Core	14	13	13	13	14	24	17	
F4T	Shell	14	25	23	23	19	19	19	
	Core	13	14	11	15	14	25	17	
F4B	Shell	14	21	18	21	20	24	25	
	Core	14	15	15	16	17	18	21	

*Kinds and amounts of food storage varied with different reading dates; i.e., on July 15, 1966, fruit was stored at 75 percent of storage capacity and at -10° F.

The importance of the effects of special interior environments is in no sense limited to timber structures. High humidity affects most wood-based products, whether they are structural subflooring, underlayment, insulation, acoustical, or the many varieties of finish panels. Humidity and its companion, condensation, can be equally damaging to many nonwood materials, and increased understanding of interior environments has broad pertinence to designers and manufacturers of all building materials.

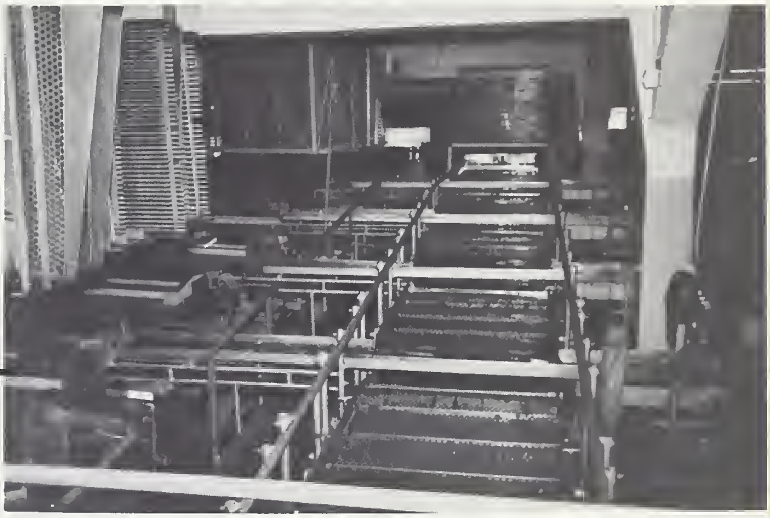


Figure 21.--Wet sorting conveyor is operated seasonally and entire area is hosed down after each shift. Sawn beam over this conveyor varies in moisture content with the pattern of operation. (Washington Canners Coop., Vancouver, Washington.)

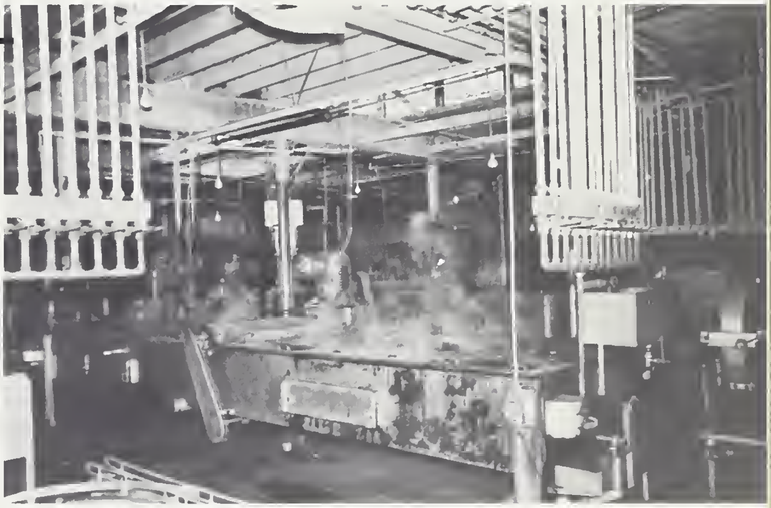


Figure 22.--Though not immediately above the cooker shown, this glulam beam is enveloped by steam from its operation and condensation forms in beads on its surfaces. Cookers are also operated seasonally with the sorting operation. (Washington Canners Coop., Vancouver, Washington.)

Figure 23.--Refrigerated storage space is operated from -10° F. for frozen goods to 35° for temporary storage and is completely washed down and fumigated between loads. The moisture load of the stored vegetables is variable in this example. (Washington Canners Coop., Vancouver, Washington.)

DISCUSSION

These exposure types are not always clearly defined in practice, and transitional variations frequently occur between them. Thus, an exterior member may be afforded varying degrees of protection from sun and rain by an overhang, shelter, or flashing, and wind-driven rain or capillary moisture may penetrate protective elements. Similarly, a normal interior occupancy may be opened in varying degrees to summer breezes and an exterior atmospheric environment. Among the subjects listed, building G is a clear example of a structure influenced by both exterior atmospheric conditions and the ice rink it contains, making it some combinations of types II and IV. It is listed under the former because of its open character and the absence of complete enclosure to isolate a special environment, but the presence of the ice appears to be a strong influence on the resulting moisture contents.

Climate in Washington and Oregon varies from the coastal strip of heavy rainfall to arid basins east of the Cascade Range (7). As the more arid regions are duplicated in other areas of the national program, this study is confined to the predominantly marine-type climate west of the Cascades. Western Oregon and Washington was divided into a coastal area west of the Coast Ranges where annual rainfall exceeds 100 inches in some localities, and a more populous valley area extending from Puget Sound southward through the Willamette River valley of Oregon.

Though both of these areas are influenced by humid air from the Pacific Ocean, there are distinct differences in the extent of rainfall and the seasonal occurrence of high humidity. Although considerable humidity from ocean breezes persists in the coastal area through the summer months, a relatively dry late-summer period in August and September is typical in the valley area.

Accordingly, installations have been made in both areas to discover whether these climatic differences are significant in their influence on structural timbers. The limited data reported here indicate no significant differences in moisture content under similar exposure conditions in these two areas.

SUMMARY

Preliminary results of this study in western Washington and Oregon generally confirm current industry standards and recommendations (*2*) for the design of glulam structural members. However, indications are that existing classifications of exposure do not fully cover all possible use conditions, and that the application of present standards frequently must depend on engineering judgments in areas where field data are lacking.

Present results confirm the need in this region for waterproof adhesives and reduced allowable design stresses in exposed structural members. Saturated conditions frequently occur near connections, end-grain surfaces, and checks. Depending upon the design life of the structure, this condition suggests consideration of naturally durable species or preservative treatment in all but the most favorable design circumstances. A large field for study exists to evaluate and develop protective covers, flashings, treatments, and coatings which are sufficiently effective and permanent to reduce the risk classification of exterior members. Standards of design in this area are presently dependent upon subjective evaluations.

Conventional heated interiors produce low moisture contents in a narrow range, but the widely varying special interior occupancies may result in severe interior "weather" conditions. These conditions can be controlled by design, but additional study of many factors is needed to develop reliable methods.

Climatic differences between the coastal and valley areas do not appear significant in their effect on the moisture content of wood members.

It is already possible to identify many of the principal design problems affecting the satisfactory performance of glulam members exposed to severe environments. To this extent, the preliminary results of this survey are significant, and their publication invites the timely comments of members of industry in guiding the future emphasis of the continuing study.

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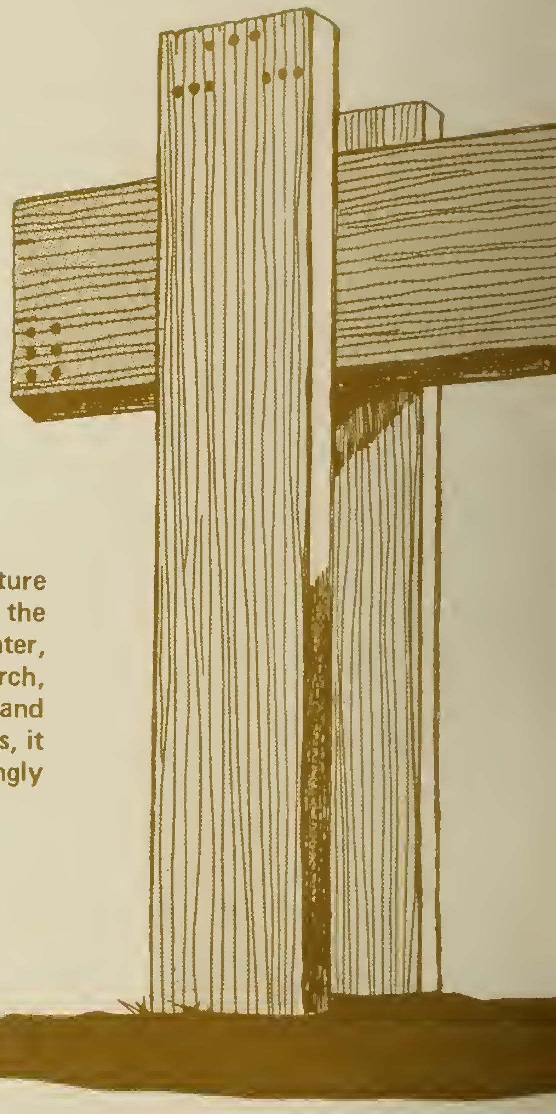

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